

Analyzing the characteristics of 6 MV photon beam at low monitor unit settings

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ABSTRACT

Analyzing the characteristics of a low monitor unit (MU) setting is essential, particularly for intensity-modulated techniques. Intensity modulation can be achieved through intensity-modulated radiotherapy (IMRT) or volumetric-modulated arc therapy (VMAT). There is possibility for low MUs in the segments of IMRT and VMAT plans. The minimum MU/segment must be set by the physicist in the treatment planning system at the time of commissioning. In this study, the characteristics such as dose linearity, stability, flatness, and symmetry of 6 MV photon beam of a Synergy linear accelerator at low MU settings were investigated for different dose rates. The measurements were performed for Synergy linear accelerator using a slab phantom with a FC65-G chamber and Profiler 2. The MU linearity was studied for 1–100 MU using a field size of 10 cm × 10 cm. The linearity error for 1 MU was 4.2%. Flatness of the beam was deteriorated in 1 MU condition. The beam stability and symmetry was well within the specification. Using this study, we conclude that the treatment delivered with <3 MU may result in uncertainty in dose delivery. To ensure the correct dose delivery with less uncertainty, it is recommended to use ≥3 MU as the minimum MU per segment in IMRT and VMAT plans.

Key words: Flatness; gated volumetric-modulated arc therapy; linearity; low monitor unit; stability; symmetry

Introduction

Intensity-modulated technique has become the main treatment modality in radiotherapy. Intensity-modulated plans can be delivered through step-and-shoot intensity-modulated radiotherapy (IMRT), sliding window IMRT, or volumetric-modulated arc therapy (VMAT). In step-and-shoot IMRT, the beam is held for a while in between the segments for multi-leaf collimator (MLC) to make the next segment. In sliding window IMRT and VMAT, the beam is continuously on while the MLC are moving. A faster delivery of treatment can be achieved by VMAT with the same quality of IMRT plans.^[1-3]

VMAT is the enhanced version of IMRT in which gantry, MLC, and dose rate are continuously changing during treatment. The dose rate changes can also be observed in sliding window IMRT. In all IMRT and VMAT plans, the monitor unit (MU) for the segment was assigned while doing optimization. There is a chance for the presence of low MU in the segment. The acceptable minimum MU per segment for IMRT and VMAT plans must be defined by the physicist in the treatment planning system (TPS). This parameter is used by the planning system while assigning MU for the segment while doing optimization. The system always verifies that the MU for a particular segment is greater than or equal to the defined MU. The dosimetric parameters of low MU settings must be analyzed, before setting the minimum MU per segment in the planning system.

Several researchers have reported the characteristics of low MU such as stability, linearity, flatness, symmetry, and

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reproducibility for various linear accelerators from Elekta, Siemens, and Varian.^[4-13] Different results were reported for the same make of the linear accelerator, which revealed that the characteristics of the beam differ between the machines.

In this study, the analysis of dose linearity, stability, flatness, and symmetry of 6 MV photon of the Synergy linear accelerator under low MU condition was performed. Mohr *et al.*^[5] and Fujimoto *et al.*^[11] have investigated the characteristics of Elekta linear accelerator at low MU condition. However, since varying results have been reported for machines of the same model, this study was performed to analyze the individual characteristics of our machine and to define the minimum MU per segment for IMRT and VMAT plans in TPS.

Materials and Methods

Linac and record and verify system

The Synergy linear accelerator (Elekta Ltd., Crawly, UK) is equipped with three photon (4, 6, and 15 MV) and seven electron (4, 6, 8, 10, 12, 15, and 18 MeV) energies and MLCi2 model collimation system with 40 pairs of MLC, 1 cm resolution at the isocenter. The maximum field size coverage is 40 cm × 40 cm; the maximum gantry speed is 6°/sec. A 6 MV photon energy was used for this study with a binned dose rate up to 600 MU/min (i.e., 9, 18, 37, 75, 150, 300, and 600 MU/min) since continuous variable dose rate is not available in the machine. MOSAIQ Version 1.60 × 6 (IMPAC Medical Systems, Inc., Sunnyvale, CA, USA) was used as a record and verify system.

Dose linearity

Linearity of MU was analyzed for 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 30, 40, 50, and 100 MU by recording ionizing reading for 6 MV photon using a 10 cm × 10 cm field size. The FC65-G ion chamber (IBA Dosimetry, Germany) was placed at a depth of 10 cm in the plastic water (density = 1.03 g/cc) slab phantom (Nuclear Associates, USA) measuring 30 cm × 30 cm × 30 cm. The electrometer NE 2580/1 (NE Technology, UK) was used for charge measurement. The source to skin distance (SSD) was set at 100 cm on the surface of the phantom. Three sets of readings were recorded for each MU for the dose rates of 300 MU/min and 600 MU/min. The linearity error was calculated using the following formula:

$$\text{Linearity error} = \frac{L - L_{\text{avg}}}{L_{\text{avg}}} \times 100$$

Where, L - charge per MU; L_{avg} - mean charge per MU for all measurements.

Monitor unit stability

There is a chance for beam termination in between the treatment due to some problem in the linear accelerator (e.g., MLC position mismatch, voltage problem, etc.) or miscommunication between console and record and verify system. Otherwise, the beam may be interrupted

automatically/manually by the technologist to implement the gated IMRT/VMAT techniques. This may lead to small dosimetry inaccuracy due to rounding of part MU delivered in the first portion of treatment. Therefore, the stability of the beam must be analyzed for interruption. To study the stability of MU, the same experimental setup for dose linearity was used. The ionization readings for 10 MU and 20 MU were recorded without interruption. The beam was interrupted for 5, 3, and 2 times for 10 MU and 10, 5, 4, and 2 times for 20 MU. The cumulative readings were recorded for 300 MU/min and 600 MU/min.

Stability of flatness and symmetry

The beam flatness and symmetry for low MU was studied using Profiler 2 (Sun Nuclear Corporation, Melbourne, USA). It consists of 139 diode detectors with 4 mm resolution. Diode detector sensitivity is 32 nC/Gy. The maximum field size that can be measured is 22.4 cm in cross-plane and 32.8 cm in in-plane. In this study, the profiler surface was maintained at 100 cm SSD with field size of 10 cm × 10 cm. The in-line and cross-line profiles were acquired for the range 1–100 MU for all dose rates. The flatness was calculated using 'variance' method and symmetry was calculated using 'area' method.

Results

Dose linearity

The dose linearity graph between delivered MU and measured doses for 300 MU/min and 600 MU/min is shown in Figure 1. Table 1 shows the linearity error for both the dose rates. Linearity error was 4.2% when 1 MU was delivered and it was reduced to <2% when more than 1 MU was delivered. The results were similar for both 300 MU/min and 600 MU/min dose rates.

Monitor unit stability

The doses for 10 MU and 20 MU were recorded with and without interruption. The percentage of variation with and without interruption was analyzed. The variation is <1% for both 300 MU/min and 600 MU/min dose rates. Figure 2 illustrates the result of MU stability.

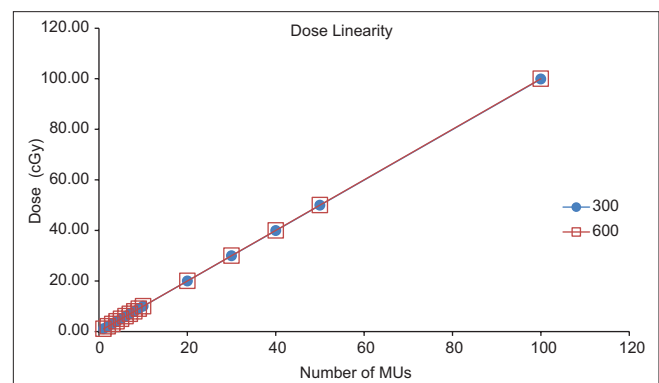


Figure 1: Dose linearity for the dose rates 300 MU/min and 600 MU/min

Stability of flatness and symmetry

No variation was observed in symmetry of the beam while using low MU. However, the flatness of the beam deteriorated as MU decreased to one with low dose rate (300 MU/min). Figures 3 and 4 illustrate the result of flatness and symmetry at low MU condition.

Discussion

Several authors have reported the dose differences at low MU delivery for Elekta, Siemens, and Varian linear accelerators. Some authors reported very high uncertainty in linearity at low MU condition. Ravikumar *et al.*^[4] reported 20–40% of dose difference at low MU condition (using 6 MV and 18 MV) for Siemens Mevatron KDS linear accelerator. Reena *et al.*^[7] also reported a linearity error of –32% for 6 MV and –13.5% for 18 MV with regards to Siemens Primus machine.

Bhangle *et al.*^[6] conducted a study on 6 MV and 15 MV photon for Siemens Oncor impression linear accelerator

and indicated only 2% variation in linearity for ≥ 2 MU and around 12% variation for 1 MU. Kang *et al.*^[10] revealed more than 10% dosimetric variation for low MU in Varian 21EX machine. The beam symmetry and flatness deteriorated as MU decreased to 1. Mohr *et al.*^[5] reported only 2% variation for 6 MV and 15 MV, whereas Fujimoto *et al.*^[11] reported that standard deviation was within about $\pm 5\%$ for 1 MU and these variations were reduced to $\pm 1.2\%$ from 2 MU per segment for Elekta machine.

Our results revealed that linearity error for 1 MU was high (4.2%) for both the dose rates of 300 MU/min and 600 MU/min. The reason may be that, in Elekta machine, only the first segment is initiated by the electron gun and magnetron, from second segment onward, the beam is initiated from the magnetron only. Reena *et al.*^[7] and Kang *et al.*^[10] also reported very high variation (32% and 4.5%, respectively) for 1 MU and the uncertainty was reduced while delivering high MUs. Our results showed the similar beam behavior for linearity.

In this study, the symmetry of the beam profile was within the specification for both the dose rates. Large variation in symmetry was not reported even for 1 MU in any referred studies. Bhangle *et al.*^[6] reported a maximum of 3.4% variation for 1 MU and $< 2\%$ of variation for ≥ 2 MU.

Flatness of in-plane profile was within 3% for ≥ 3 MU whereas 3.8% for 1 MU and 3.1% for 2 MU. Bhangle *et al.*^[6] reported 4.88% variation for 15 MV at 1 MU, and within 2% variation for MUs above 2.

Many researchers gave various recommendations for the minimum MU per segment. Reena *et al.*^[7] Bhangle *et al.*^[8] and Miura *et al.*^[13] recommended ≥ 4 MU, < 5 MU, and 5 MU, respectively. Our results showed that the treatment delivered with < 3 MU settings can result in an error in dose delivery. Therefore, ≥ 3 MU should be used as the minimum MU per segment for the Synergy machine.

Table 1: Dose monitor linearity error at different monitor units

MUs	Dose in cGy (MU/min)		Dose/MU (MU/min)		Linearity error (MU/min)	
	300	600	300	600	300	600
	1	1.035	1.035	1.0400	1.0400	4.198
2	1.996	2.033	1.0000	1.0150	0.190	1.693
3	2.995	2.995	0.9970	0.9970	-0.110	-0.110
4	3.956	4.030	0.9900	1.0075	-0.812	0.942
5	4.954	5.028	1.0060	1.0060	0.792	0.792
6	5.989	6.026	1.0050	1.0050	0.691	0.691
7	6.987	6.987	0.9986	0.9986	0.050	0.050
8	7.986	7.986	0.9988	0.9988	0.070	0.070
9	8.984	8.984	0.9978	0.9978	-0.030	-0.030
10	9.982	10.019	0.9980	1.0020	-0.010	0.391
20	19.964	20.001	0.9980	1.0000	-0.010	0.190
30	29.946	30.020	1.0000	1.0000	0.190	0.190
40	39.891	40.002	0.9970	1.0000	-0.110	0.190
50	49.910	50.020	1.0000	1.0000	0.190	0.190
100	99.856	100.004	0.9986	1.0000	0.050	0.190

MU: Monitor unit

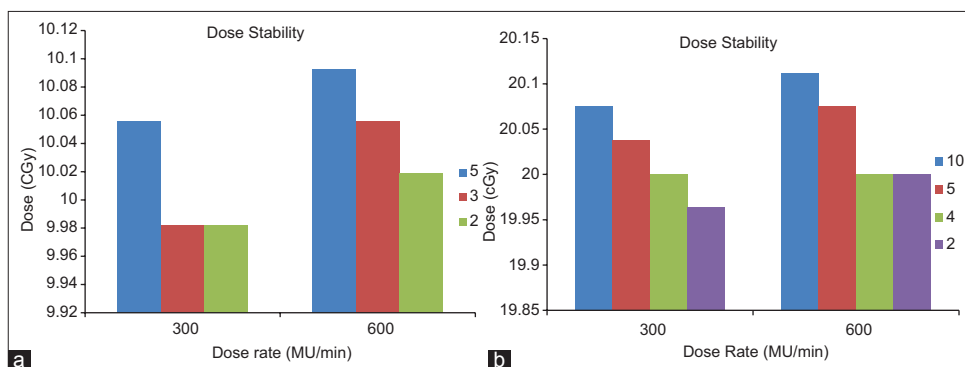


Figure 2: (a) Dose stability for 10 monitor unit with 2, 3, 5 interruption (b) 20 monitor unit with 2, 3, 5, 10 interruption

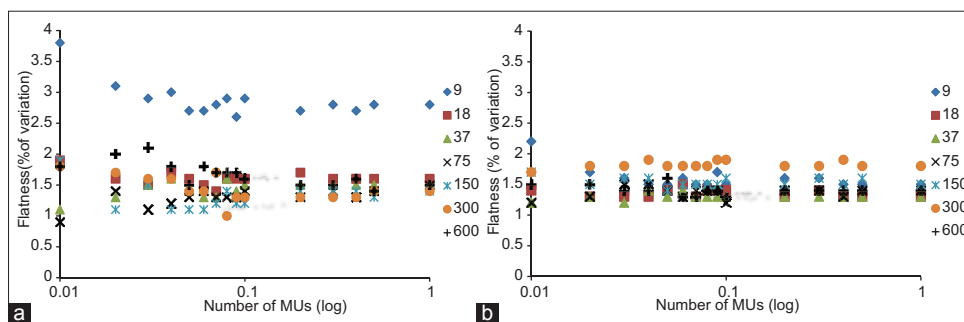


Figure 3: (a) Flatness (in-plane) and (b) Flatness (cross-plane) of the beam at low monitor unit (values are from 1 to 100 monitor units for different dose rates)

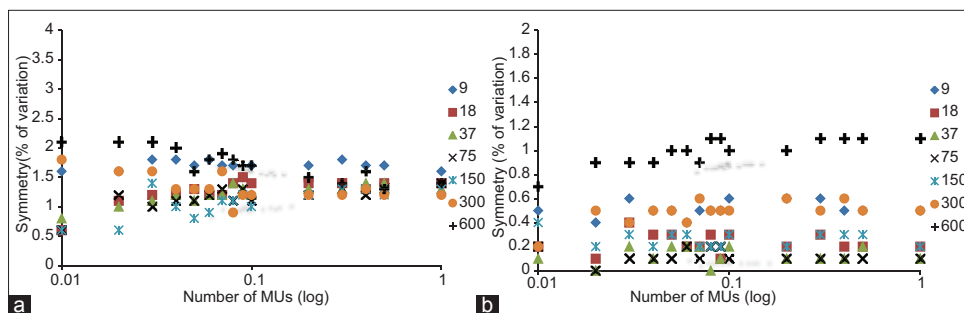


Figure 4: (a) Symmetry (in-plane) and (b) Symmetry (cross-plane) of the beam at low monitor unit (values are from 1 to 100 monitor units for different dose rates)

Conclusion

The dosimetrical characteristics such as linearity, symmetry, flatness, and stability of 6 MV photon at low MU settings were evaluated. Based on the findings of this study, we conclude that a treatment delivered with <2 MU may result in an error in dose delivery. To ensure the correct dose delivery with less uncertainty, it is recommended to use ≥ 3 MU as the minimum MU per segment in IMRT and VMAT plans.

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Conflicts of interest

There are no conflicts of interest.

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